ANALYSIS AND VALIDATION OF AN INTELLIGENT ENERGY MONITORING FRAMEWORK FOR A YACHT POWERED SYSTEM BASED ON ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM (ANFIS)

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ABSTRACT

The application of artificial intelligence (AI) has been improvised in various sectors, but one such sector which still remains unexplored is the yacht energy administration system. This work particularly deals with furnishing a framework for a hybrid able power management system for yacht electric systems. The framework was prepared and developed with the aid of the Adaptive Neuro-Fuzzy Inference System (ANFIS). The study basically deals with regulating battery usage with the aid of ANFIS which present an intelligent way of finding the relationship between various operating factors and their immediate outputs. The average testing error was as low as 4.2 RSME value. Also, various membership functions in ANFIS are selected and the best among them is suggested for further analysis which was the trapezoidal membership function with an error rate of 0.00068. Application of AI in yacht operating system will aid in providing sustainable solutions in cost-effective and efficient manner, thereby safeguarding the environment from harmful exhaust effluents and simultaneously improving the sailing period.

KEYWORDS: Artificial Intelligence, Yacht Engine, Electric Engine, Optimization & ANFIS

Original Article

1.0 INTRODUCTION

To operate fossil fuels and gas turbines conventional maritime power plants are designed, which are the main contributors of oxides of nitrogen and are the prominent causes of unburnt hydrocarbons (UBHC) from COx and suspended particles triggering air contamination and lowering yacht operating costs [1-3]. Researchers in recent times have begun to examine the quality of the air in the Pearl as a result of ongoing yacht emissions, as well as the properties of exhaust emissions and the consequences of maritime air pollution emissions. Sustainable-fuel alternatives such as liquefied natural gas (LNG), natural methanol, and bio-ethanol along with sustainable energy resources, solar and wind power, fuel cells, and hydrogen fuel must be suggested in place of fossil fuels. Implementations for yacht power plants must be postulated [4-7].

The goal of conserving energy and lowering yacht emissions can be accomplished by Renewable energy resources, but utilizing only a single source of energy can't be a reasonable approach since it is influenced by changing meteorological conditions [8-10].To monitor and restrict the overall greenhouse gas discharges from yachts the International YachtOrganization (IMO) has allowed the use of sustainable energy in a variety of applications. As a result, yacht manufacturers began to follow the trend of non-emitting yachts. Furthermore,

utilizing fully independent yachts that can work for extended periods of time without needing to refuel. In comparison to fossil fuel energy, sustainable energy powers the boats electrical system with higher efficiency, low acoustics, and almost nil effluents of pollutants. Green energy has become a requirement, and the All-Electric Yacht (AES) technology, which is proceeding towards substituting the yacht's power mechanism with electrical energy sources that are non-polluting, secure, cost - effective, and convenient sources that are reusable sources of energy such as solar, air, and fuel-cell systems, has become mandatory. The wider regions of ports were polluted by yacht board pollutants when berthing, so the US Navy introduced the European project EL-EMED, named as the initiation of "cold ironing" in the East Mediterranean to alleviate the harbor from yacht's toxic pollutants and to assist the effort by moving toward "green and sustainable" energy (e.g. renewables) [11-13]. Because it has high dynamic capability and reliability, utilizing fuel cells for maritime propulsion systems has emerged as a new contender inside the yacht power mechanism, and it is suggested in the maritime industry [14].

Regulating the energy of fuel cells, on the contrary, is a concern, thus fuel cells are employed as an alternative supply in different electricity-based sector approaches and particular tasks in navy yachts that requires a reduced acoustical signature, such as sub-yacht hunting. Power storage technologies such as super-capacitors and batteries enhance the kinetics and power efficiency of fuel-cell systems that necessitate their integration. Another method for improving the effectiveness of the fuel cell hybrid power system is to incorporate a sustainable photovoltaic system, which can cut fuel usage by up to 50%. A power management strategy (PMS) is used to optimize the mechanism in order to achieve cost-effective fuel use and guarantee that the workload receives enough energy [15-17].

Another consideration is to extend the lifespan of each hybrid energy system as much as feasible. The rapid progress of artificial intelligence techniques was spurred by the advancement of power networks that employ renewable sources of energy, as well as the breakthrough in power electronics.AI technology in power station operations, propagation, transition, preservation, and management, enhances power system stability, output quality, and system protection over traditional protective methods. The system introduced in this paper is state-of-the-art as well as the most widely utilized system in many industrial, aeronautical, commercial, and as well as military occupation, terrestrial, maritime, and, most recently, in the system of traction. The energy is what distinguishes the two systems method of management procedures. The benefits of fuzzy and neural techniques can be merged by using an intelligent adaptive neuro-fuzzy inference structure in a yacht power system. These processes are used to identify the schematic Fault Diagnosis, evaluate the system value, create the power effectiveness of the system, and most recently to accomplish the energy produced by the hybrid system to achieve the most efficient use of energy with the maximum system performance. The yacht's energy management system is similar to any other power system and begins the upgradation with a territorial power system [18-20].To determine the appropriate energy cell power as system productivity depending on solving the optimization issue to decrease fuel consumption and guarantee system balance, the load requirement and batteries state of charge (SOC) are the (EMS) inputs in this framework.

The intelligent grid technology, imperative integration in artificial intelligence (AI) and computing intelligence, has answers to sophisticated challenges caused by the presence of different inputs-outputs in integrated arrangements. Also, greater the quantity of data for the thrust system, operational equipment, and weapons system navy yachts must be analyzed to make a conclusion, AI and CI offer optimal solutions through centralized or shared intelligence. A massive quantity of input is processed in micro-grid system with computation intelligence (CI) to aid decision-making. Artificial

intelligence mimics a human brain's decision-making skills, including search strategies, information processing, reasoning techniques, and machine learning. Adaptive techniques, such as the capacity to change and generalize, are included in CI for intelligent behaviors in complicated networks. These approaches introduce a new competitor to the area of yacht smart grids and computer-assisted power technology. For yacht board operations, servicing, surveying and risk management AI and CI can prove to be the most effective tools. Yacht smart grid solutions to address the unpredictability, growing complexity, and extremely irregular characteristics of hybridized electrical power networks for functions yacht smart grid solutions can be of immense use.ANFIS is often applied in various researches which requires the integration of artificial Intelligence approach which simulates humanoid brain activity [21].

ANFIS may be described a scientific model of the humanoid brain circuitry due to its education and adaptable abilities. The precision of the power handling in naval electric yachts is critical for ensuring power availability in all operation modes. A fuzzy framework arrangement that employs a flexible knowledge method for training is known as the adaptive neuro-fuzzy inference system (ANFIS).ANFIS is a strong approach for adaptive control and power optimization in essential applications like hybrid smart grid, as well as in platforms that include a fuel cell and a battery for various purposes. To allow these systems to be easily interfaced for navigation the Internet of things is used, particularly in naval and independent yacht operations in harmful or unsafe regions, with a secure communication network for management and distant control.

2. SYSTEM DESCRIPTION

The suggested concept is a standard blended prototype that includes a fuel-cell as the primary Dc power supply and a battery deposit and super-capacitor storing device. Depending on the yacht's usage and load requirement the type is improved by inclusion of additional sources of energy, such as a solar power source(PV module) or a bio-diesel based engine unit. The intended integrated framework is focused on the energy requirements for stealth operations. The lack of mechanical hardware leads to a minimal acoustical signature for the design. The setup, which includes a 15kW proton conversation membrane (PCM) fuel-cell power module, is intended to fulfil the average requirement of 8 kW. In Figure 1 the envisioned Power Management System (PMS) design is depicted with the ANFIS controller having four inputs and one output. The load power $Pload$ and the battery State of Charge SoC are the inputs to the EMS, which are pumped into the EMS to detect the system's effectiveness toward the loading and compute the predicted power from the fuel cell Pfc based on the prepared data. The load within the system may be updated based on observation.
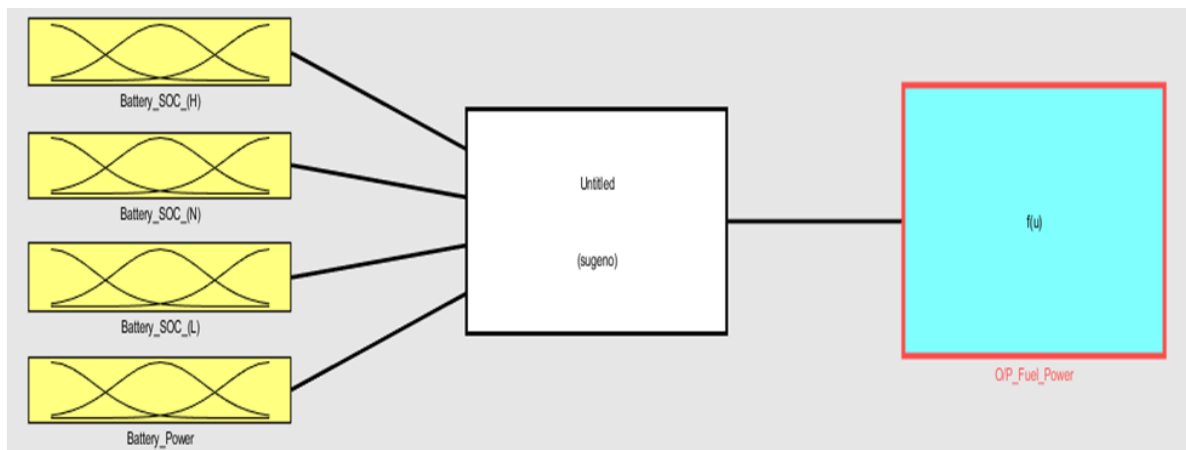
Figure 1: Power Management System Framework.

3. METHODOLOGY

At least two sources of energy are employed in hybrid models to provide the load with the power it requires. These models are generally integrated with dual sustainable energy resources, energy deposit systems, or fuel systems which can be the engine with carbon fuel or hydrogen. To determine which source delivers the load with the appropriate output or the amount of power each source must supply to decrease fuel intake and maintain the steadiness of the system hybrid system must feature an optimization approach that incorporates the (PMS) in it.

To accomplish this purpose, the best optimization and control technique is used in the integrated model components fuel cell, super - capacitors, with battery-operated to generate the calibrated power defined by the PMS depending on the load requirement. The electricity generated by the fuel cell, as well as the energy storage arrangement battery, must be translated to equal hydrogen intake. The corresponding hydrogen demand for load C is calculated as the total of fuel cell hydrogen consumption Cf_c, battery hydrogen consumption C_{bat}, and super-capacitor hydrogen consumption Cf_{sc}. The analogous scientific formula for optimizing the fuel consumption is given by:

$$P_{fc} = \min(Cf_c + k_1C_{bat} + k_2C_{sc}) \tag{1}$$

Where Pfc is the fuel cell output power, k_1 and k_2 penalty coefficients translate to hydrogenintake.

To serve commercial applications manufacturers are looking for an autonomous learning process due to the emergence of fuzzy approaches in the control systems. The Adaptive Neuro-Fuzzy Inference System (ANFIS) was an approach that merged the advantages of artificial neural networks' (ANN) learning capabilities and the reasoning abilities of principle-based fuzzy logic system to gain a comprehensive set of all types of feed-forward complex systems with monitored learning expertise. To determine the input-output connection the ANFIS approach performs a hybrid learning methodology by relying on professional expertise and input-output data.ANFIS has become impactful in designing dynamical systems, recognizing nonlinear specifications in real-time. MATLAB 18, which will be utilized in this project, delivers a comprehensive simulating and testing environment. Figure 2 depicts the MATLAB combined ANFIS framework used in this model.
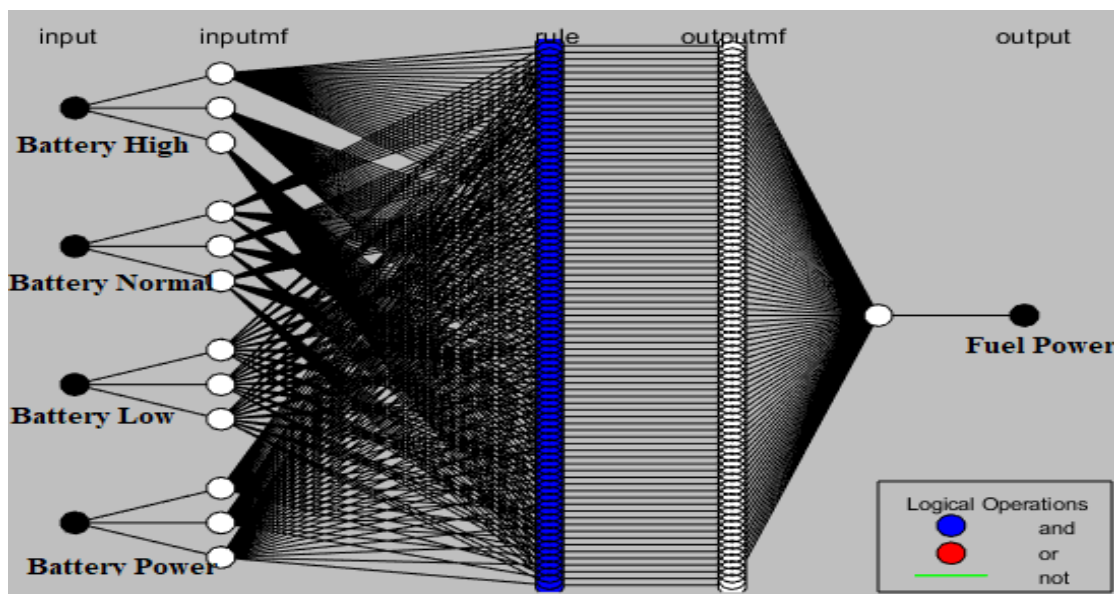

Figure 2: MATLAB Combined ANFIS Modeling.

As illustrated in Figure 2, the ANFIS design featured only one concealed layer. Layer 1 represents input node, Layer 2 represents fuzzification node, Layer 3 represents the product node (hidden), Layer 4 represents the de-fuzzification node, and Layer 5 is the output node. Furthermore, depending on whether they can be revised, certain nodes will be categorized as flexible or static nodes. Layer 2 and Layer 4 represent adaptive nodes, whereas Layer 1, 3 represents static nodes. The ANFIS uses the batteries SoC in three MF and the utilized yacht power load P_{load} to anticipate the delivery power of the fuel cell. The ANFIS outcome is the estimated production power from the fuel cell quantity PFC. The ANFIS produces guidelines and adjusts them quickly by utilizing relevant factors.

The ANFIS technique will be performed based on the learning data gained from earlier trials or human experiences, which is the advantage of employing ANFIS, particularly for dynamic organizations and framework that require a rapid conclusion at a fast pace. The general power management platform will be implemented in this system, regardless of the purpose. The mechanism with fuel cell and storage arrangement (battery, super-capacitor) may be utilized in aviation, yachts, or engine-based vehicles; the only variation is the PMS's goal. For naval yachts, the primary priority is the reliability, for automobiles, the biggest priority is decreasing fuel usage, for aircraft the primary objective is safety.

The PMS has four inputs, as shown in Figure 2. The initial feed is the battery SoC, which represents the health of the battery and the quantity of power it has; the best state is the standard state, which is within 70 and 85 percent. Another goal is to keep the battery state of charge SoC under standard SoC to extend battery lifespan.The yacht's load demand is the secondary EMS input. To preserv e system stability, the allowed fuel cell power range is 1-8 kW. The ANFIS approach includes a closed-loop operating mechanism that is based on past experience data.

ANFIS training data influences the precision of the system outcome. In this model, ANFIS is mentored to obtain different membership function (MFs) using training data from the SoC, loading power, and fuel cell energy, allowing the ANFIS to predict a strong relationship between inputs and outputs. The experienced data input-output test submitted into the software is utilized to design the control system with the least amount of error. To reduce the learning errors (1000) epochs are used for the training error is less than 0.001. This indicates that the ANFIS system result is almost as expected in terms of learning values. Table 1 depicts the output layer derived using the ANFIS with different membership functions with minimum error arte achieved in trapezoidal membership function.

Table 1: ANFIS Results with Different Membership Functions

Relationship Function	Error
Triangular	**1.93E-05**
Trapezoidal	**6.58E-06**
Cubic	**1.58E-05**
Gaussian 1	**1.58E-05**
Gaussian 2	**7.51E-06**
Polynomial	**0.00023**
Generalized Bell	**1.05E-05**

3.3 Experimental Test Procedure

The inputs of the system are Battery values as high, normal, low SoC and power. The ranges set between for all above inputs are 85-100 %, 70-85 %, 55-65 % and -1.6-3.2 %.

The test is run in three modes battery SoC over 85 percent, normal SoC in the range of 85 and 70 percent and low SoC in the range of 70 and 55 percent. For each charging process, the load is manually adjusted from 0 to 12kW, and the

ANFIS emits a signal to the DC configurable power source. The power generated by the fuel cell during the research test is displayed in table 2.

Table 2: Modeling and Analysis Table of Various Fuel Powers

| Inputs				Output
Battery soc(High)	Battery soc(Normal)	Battery soc(low)	Battery Power	Fuel Power
100	85	70	-1.6	7.3
85	70	65	0	5.5
90	80	60	1.6	6.1
95	70	65	3.2	5.9
90	85	70	-1.6	4.9
100	75	55	0	6.9
85	85	70	1.6	6.3
100	75	60	3.2	7.4
90	80	55	-1.6	6.1
95	75	55	0	5.7
95	80	65	1.6	6.7
85	70	55	3.2	7.1
95	85	70	-1.6	5.8
100	75	60	0	5.3
90	80	60	1.6	6.4
85	70	65	3.2	7.2

4. RESULTS AND DISCUSSIONS

With the aid of the above dataset, a set of rules specific number being 31 were defined which defined the relationship for various membership functions. Among these, the best membership function came out to be trapezoidal membership function with a minimum error rate of 0.0000685 which is very acceptable. The set of rules established with the data set is given in figure 3.
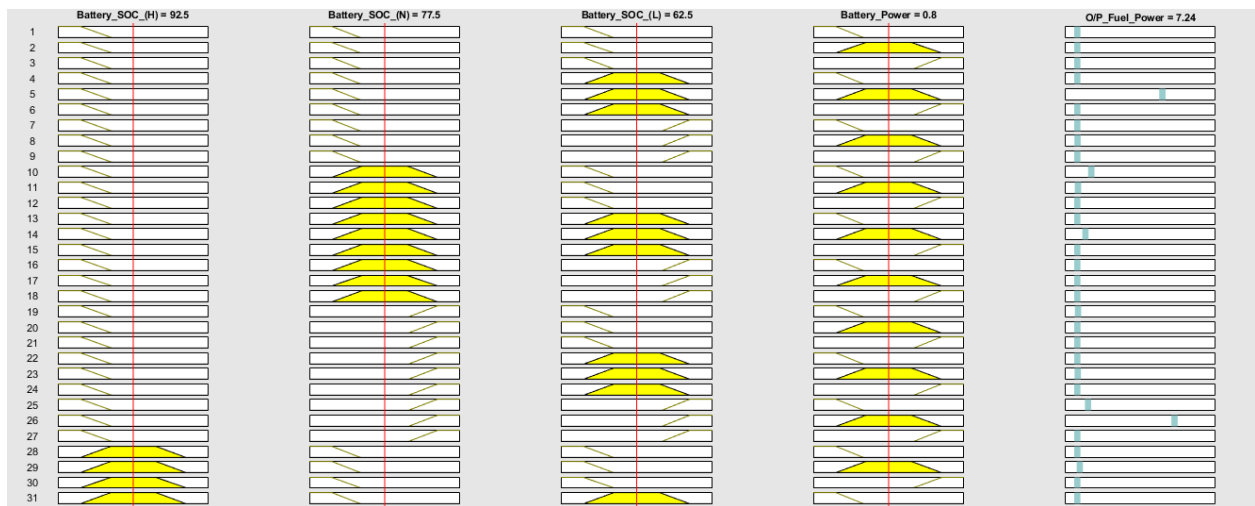

Figure 3: Rules Established for Fuel Power as Output.

The test outcomes in Table 2 are consistent with the computational results of that in high SoC, to decrease the battery SoC to standard SoC the power generated by the EMS is less than the required load power. The standard SoC is in the third column, that is nearly as powerful as the load requirement power to retain the battery SoC in standard mode. Low SoC is represented in the last column, which is used by the EMS to generate energy from the fuel cell in order to charge the

battery and provide the load. In this configuration, the battery SoC is set to 90% and the system load is increased from 0 to 8 KW. The numbers acquired in this scenario in Table 2 will be compared to the figures achieved from the simulation for the similar SoCas shown in figure 4 and figure 5.
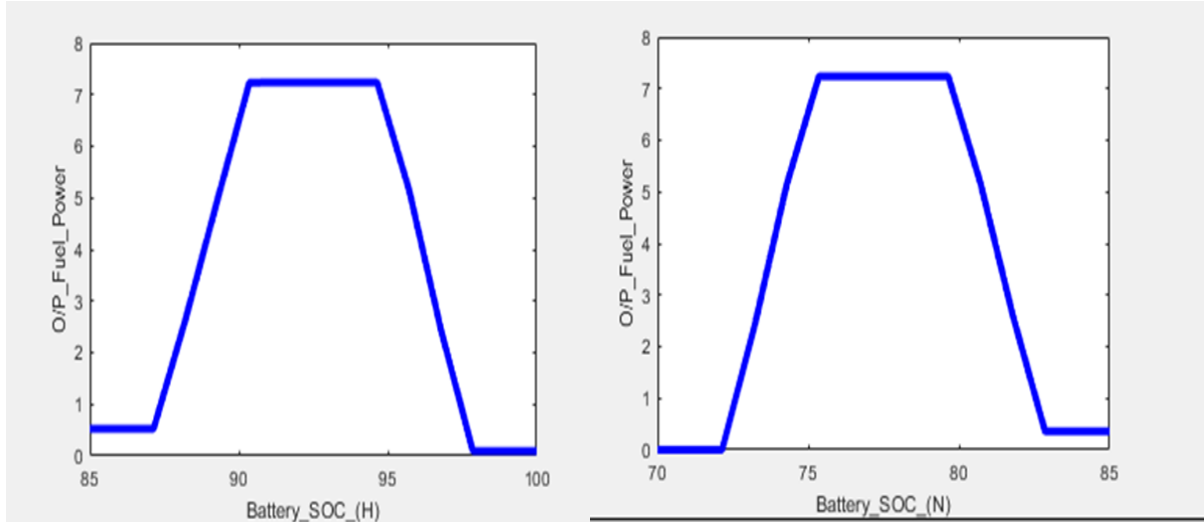
Figure 4: Variation in Fuel Power with Respect to High Battery SoC and Normal Battery SoC.
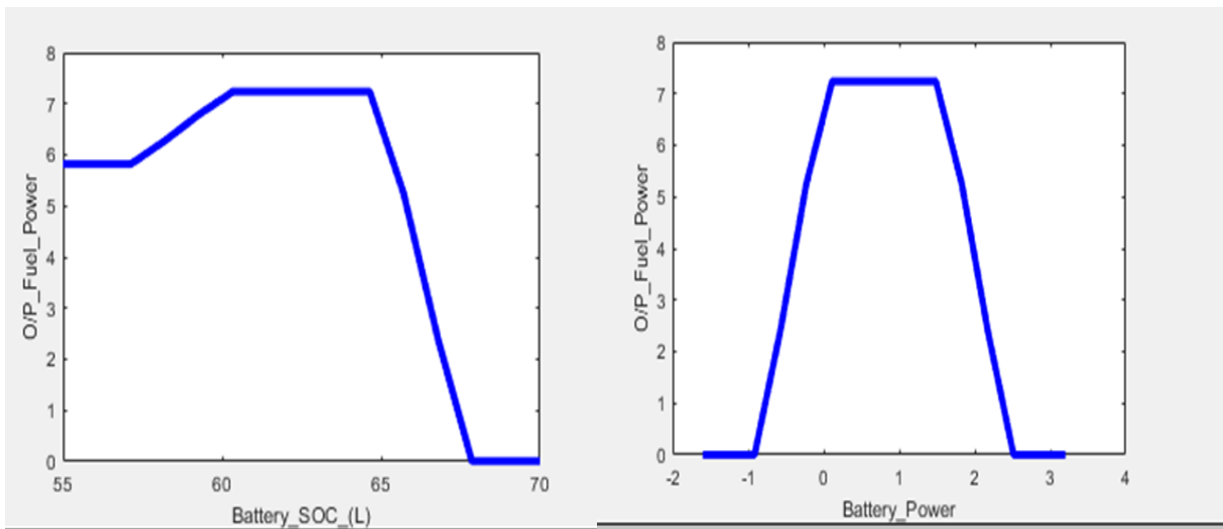
Figure 5:Variation in Fuel Power with Respect to Low Battery SoC and Battery Power.

It is quite evident from the above figures that fuel power first increases with the rise in high battery and then falls sharply with any subsequent more increase. Similar patterns were detected for normal battery also where the sharp rise was detected and then followed by a sharp fall also. In another low battery usage, fuel power decreases sharply with an increase in low battery. Maximum battery power is obtained at neutral section charging of the battery, hence indicating no overcharging in the entire process. These explanations are also validated by the three-dimensional graphs shown in subsequent parts in Figures 6, 7 and 8.
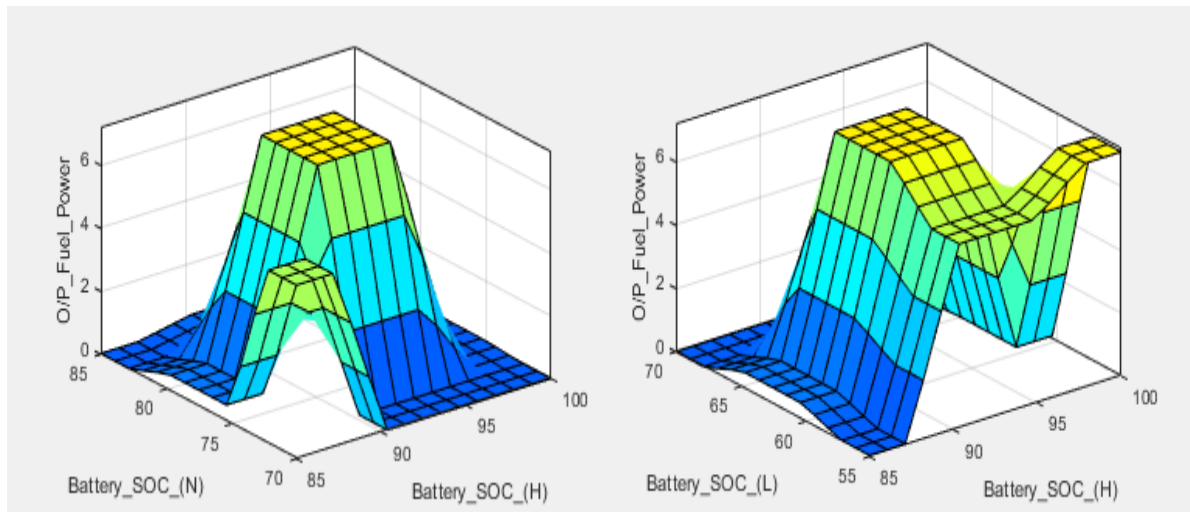
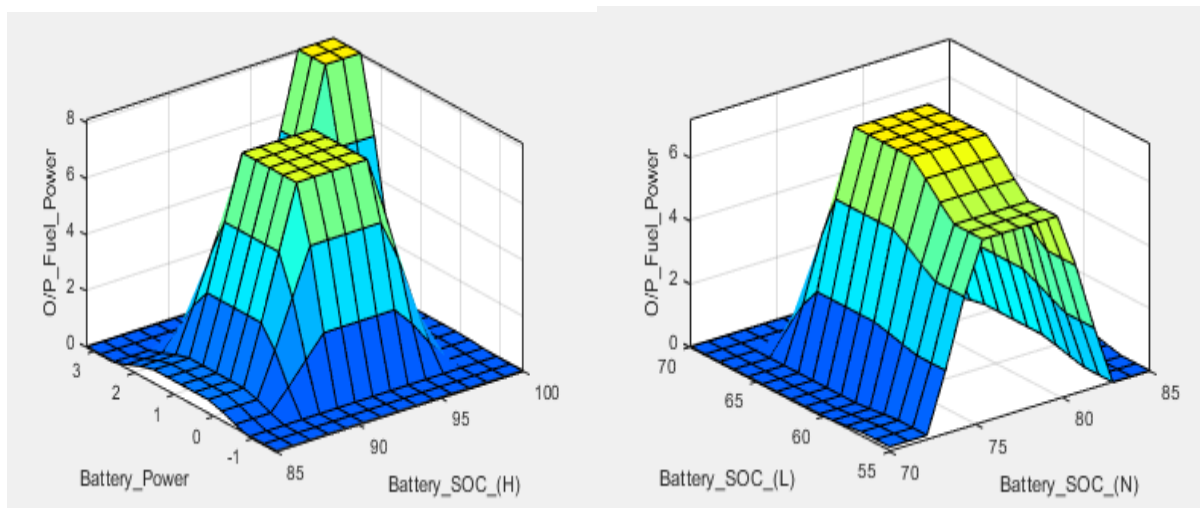**Figure 6:3: D Plot for Fuel Power Battery High, Normal and Low as Inputs.**

Figure 7:3: D Plot for Fuel Power Battery High, Normal & Low and Battery Power as Inputs.
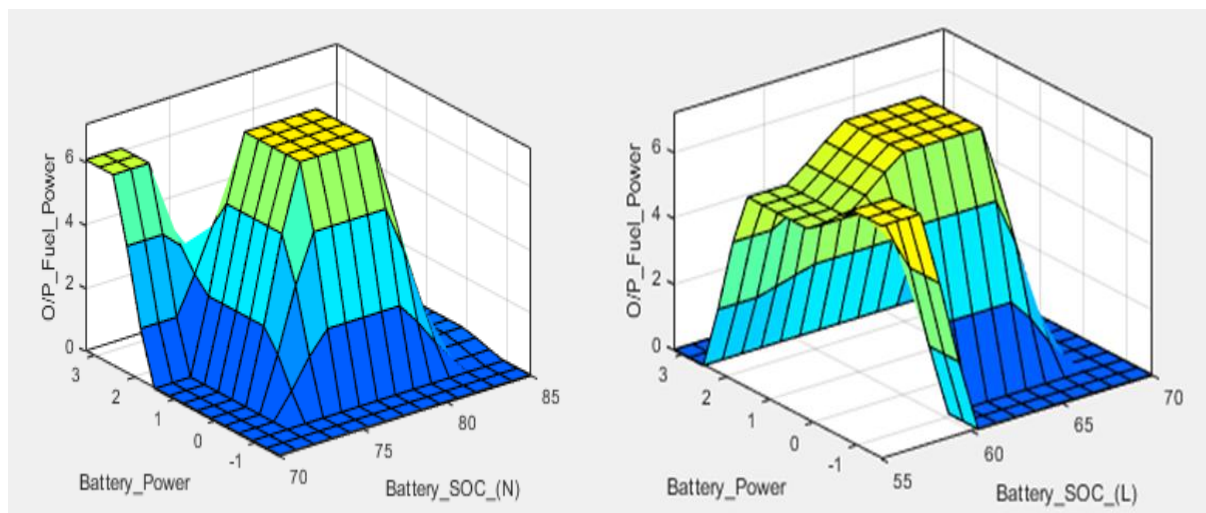

Figure 8:3: D Plot for Fuel Power Battery Normal & Low and Battery Power as Inputs.

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5. CONCLUSIONS

Particular research is established for the yacht electrified energy mechanism by utilizing both ecologically sound power resources to minimize exhaust gas pollution. Further implementing environmentally friendly energy resources according to the ANFIS procedure that blended the advantage of a neural system for mentoring and fuzzy implication for constructing a similarity for both input and output to analyze, train, and decide to solve configuration problems based on prior expertise to reduce the fuel usage. Non-conventional issues in a yacht's electrical energy system for safety, transmission, and examinations are prioritized under Smart EMS and are simple to connect with the yacht embedded power system. When installing or removing any instrument or component in the yacht energy system, the ANFIS PMS approach is more efficient and easier to adjust than standard PMS. Intuitive PMS that can be used in any system have a similar profile and require minimum change. One of the advantages of adopting advanced system approaches is that when the findings of the simulation and the outcomes of the real test are discovered to be the same, the system gains greater power. This study is a continuation of previous and upcoming research that started with the development of a hybrid power managing system, the improvement of application functionality, through the utilization of a user-operated reluctance motor as a propelling motor.

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